F-16 Microbially Influenced Corrosion (MIC) Characterization & Prevention Study

2011 Environment, Energy Security & Sustainability Symposium & Exhibition

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John Stropki
Battelle

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Overview

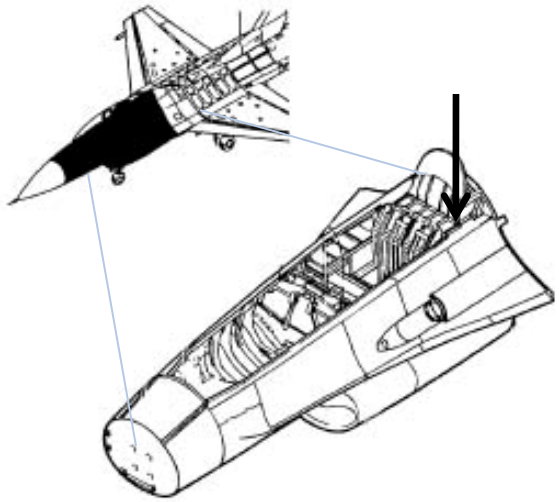
- Project Team
- Background
- Technical Approach
- Aircraft Sampling
- Microbial Characterization
- MIC Testing - Technical Approach
- Results of MIC Testing
- Mitigation Assessment
- Conclusions & Recommendations
- Points of Contact
- Questions

Project Team

- Primary Stakeholders – F-16 PO and 388th Fighter Wing
- COTR – Paul Hoth OO-ALC/GHBEX
- Program Manager – Jim Tankersley
- Principal Investigator – John Stropki
- NRL Consultant – Dr. Brenda Little
- Project Team – Dan Lorch, Annie Lane, Jill Gregory
- Additional Stakeholders
  - 508 ACSG/ENX
  - 809 MXSS/MXDEC
  - Operational Units
  - AFRL/RXBN
  - AFCPCO

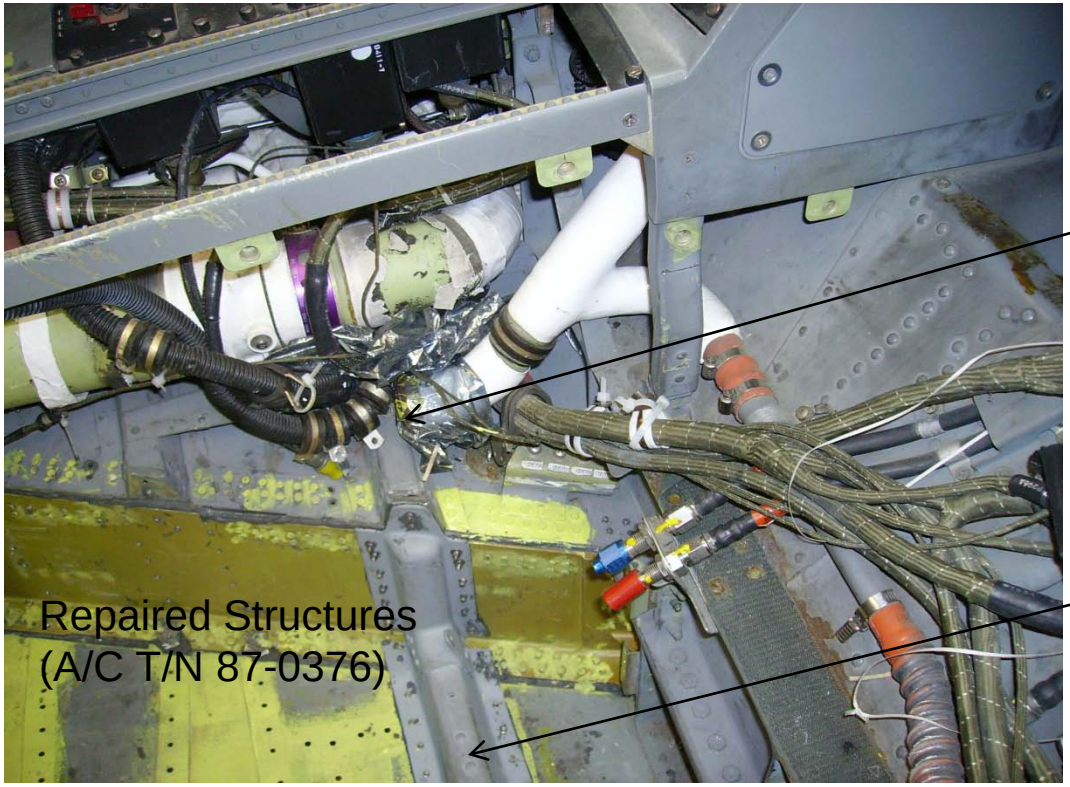
Background

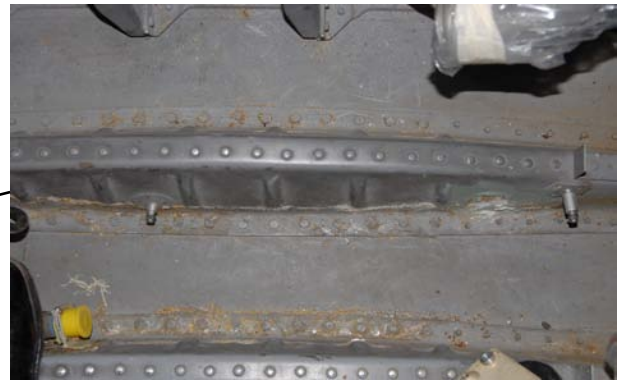
- Moisture routinely enters F-16 cockpit in different ways
  - open canopy, condensation, high humidity, Environmental Control System or ECS, etc...
- Moisture is absorbed and retained within insulation blankets used to seal lower walls and floor,
- No drain holes in aft cockpit area to remove moisture (F-16 B/D variants),
- Water collects and retained in low lying areas breaks down protective coating system and causes structural corrosion,
- Water and organic/inorganic nutrients support microbial growth.



Background (cont…)

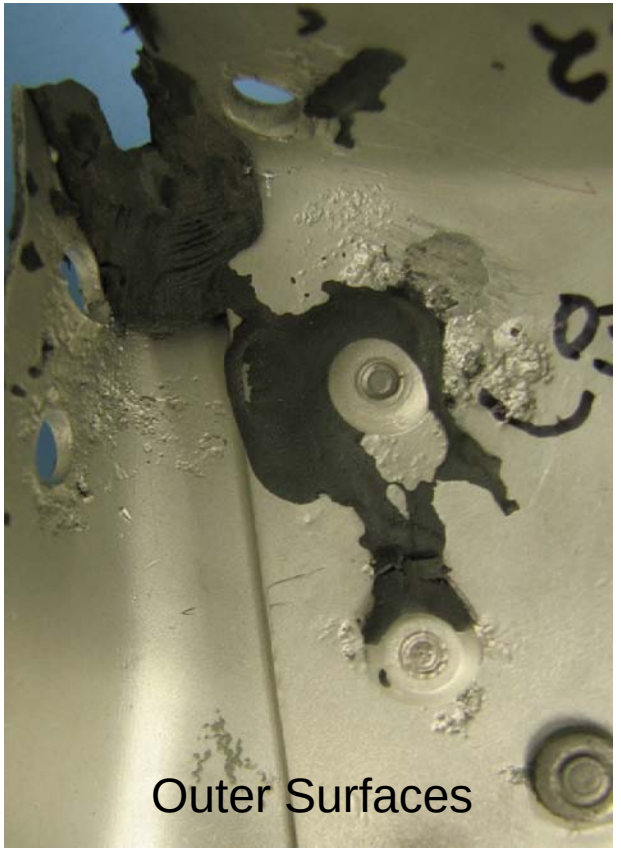
- Hill AFB representatives at F-16 World Wide Review for TCG countries stated that aft cockpit corrosion has been discovered in ~65 percent of “B” and “D” models





Background (cont…)

- Most damage confined to pitting corrosion of primary and secondary support structures
- Pitting corrosion morphology (i.e., tunneling suggests MIC



Technical Approach

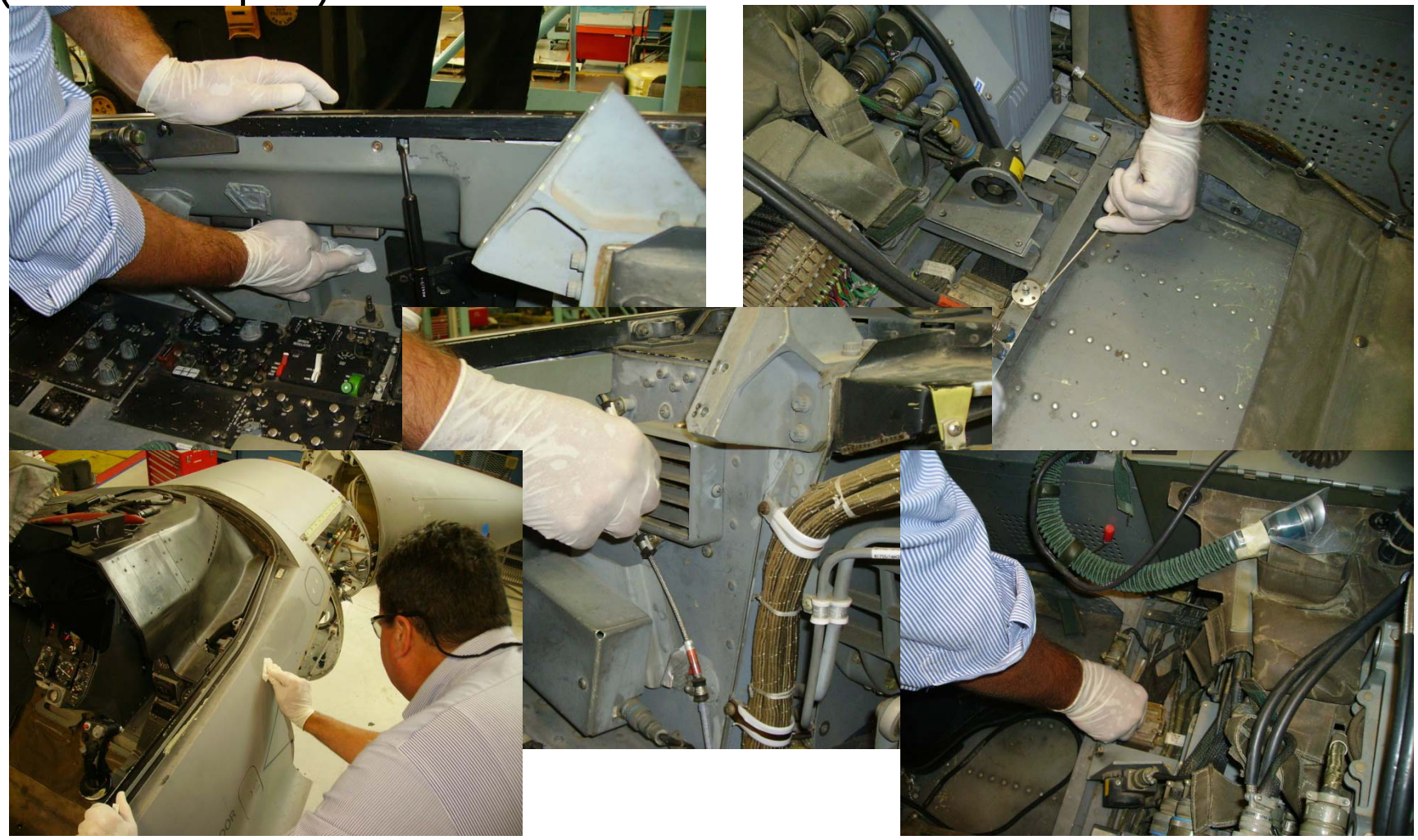
- Work with F-16 PO and stakeholder team to evaluate the potential for MIC of aircraft structures:
  - Characterize microbial species collected from aircraft
  - Validate MIC damage mechanisms under environmental conditions expected within areas of aircraft
  - Identify and assess the effect of possible short- and long-term mitigation technologies:
    - Chemical disinfection
    - Biocidal treatments and/or coatings
    - Corrosion Preventative Compounds or CPCs
    - Dehumidification

Aircraft Sampling

Condemned F-16 Aft Cockpit Component Parts

Aircraft Sampling (cont.)

- Sixty-three samples collected from similar cockpit and OML locations (control samples) on six F-16 aircraft at Hill Air Force Base



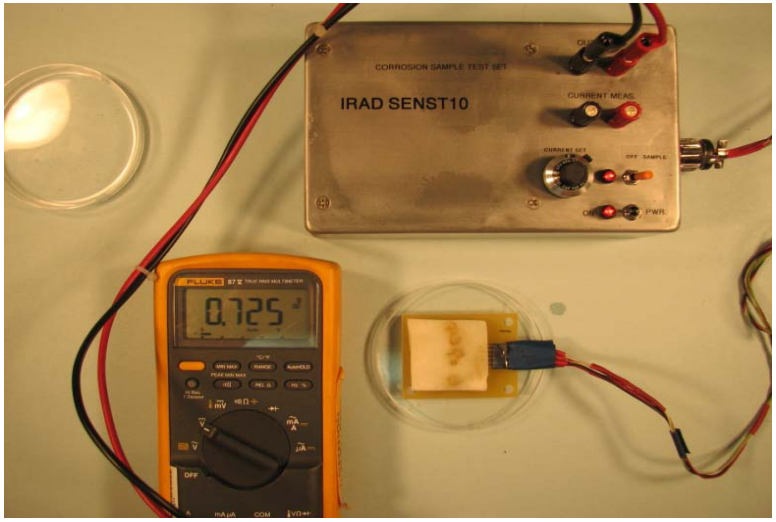
Microbial Isolates Recovered

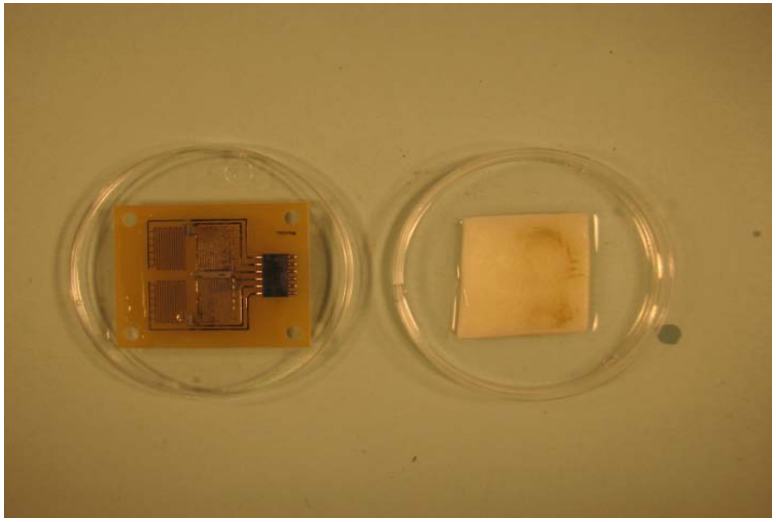
- Seventeen (17) different bacterial isolates and sixteen (16) fungal isolates recovered from the sixty-three surface samples collected from six F-16 aircraft, and nine F-16 off-aircraft component parts retrieved from aft cockpit area
- Compared microbial populations recovered from the aircraft and parts; looking for consistencies and differences of populations recovered from corroded versus non-corroded areas
- Compared microbial populations to MIC species reported in literature

Test Matrix

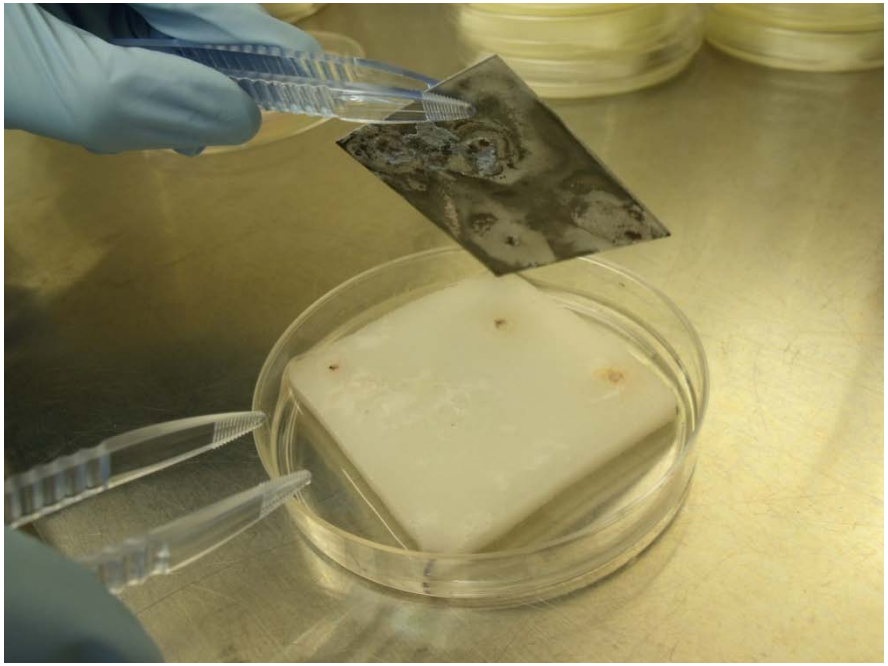
Parameter	Description
Coupon Type	2024-T3 aluminum alloy
Sensor Type	1020 low carbon steel
Incubation Conditions	26± 2C; 75-80% Rel. Humidity
Bacteria Consortium	*Microbacterium saperdae* *Rhodococcus equi* *Staphylococcus epidermidis*
Fungal Consortium	*Aspergillus fumigatus* *Fusarium oxysporum* *Penicillium oxalicum* *Rhodoturula sp.* *Trichoderma sp.*
Control Sensors and Coupons – Positive A	Dosed with microbes known to influence corrosion and used in a recent AFRL corrosion study: *Pseudomonas fluorescenscens* *Delftia acidovorans* *Enterobacter cloacae*
Control Sensors and Coupons – Positive B	Dosed with bleach, a corrosive agent
Control Sensors and Coupons – Negative	Dosed with buffer only (no microbes present)

Experimental Set-up



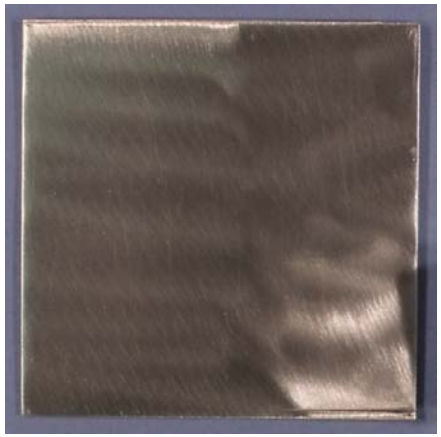


Battelle Corrosion Sensors

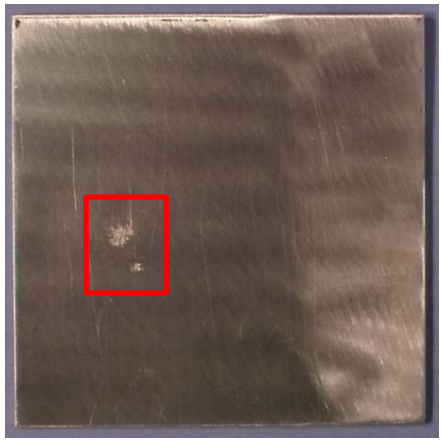


Weight-loss Coupons

Aluminum Coupon Results: 1-month Exposure, Descaled



Bacteria Consortia



Fungi Consortia

Combination

Buffer Only

Aluminum Coupon Results: 2-month Exposure, Descaled

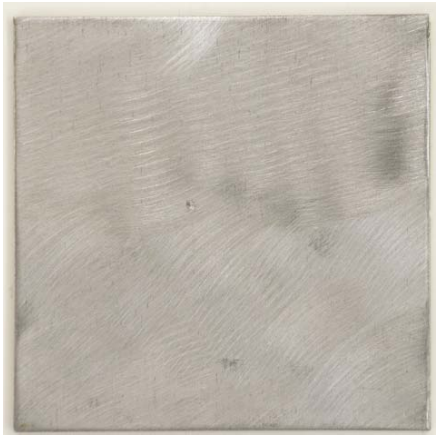
Top

Bacteria Consortia

Fungi Consortia

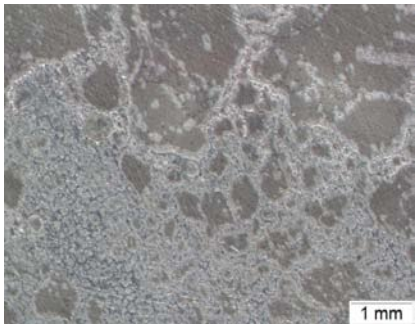
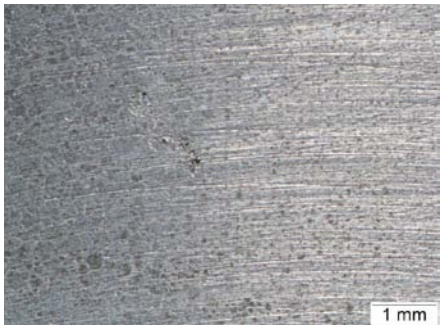
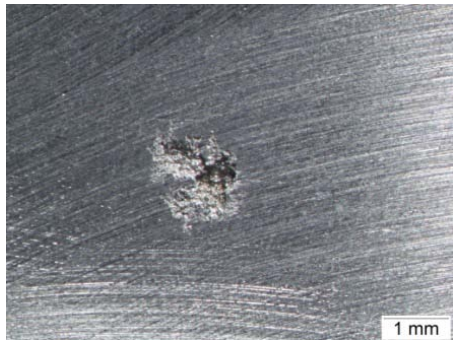
Combination

Buffer Only



Bottom

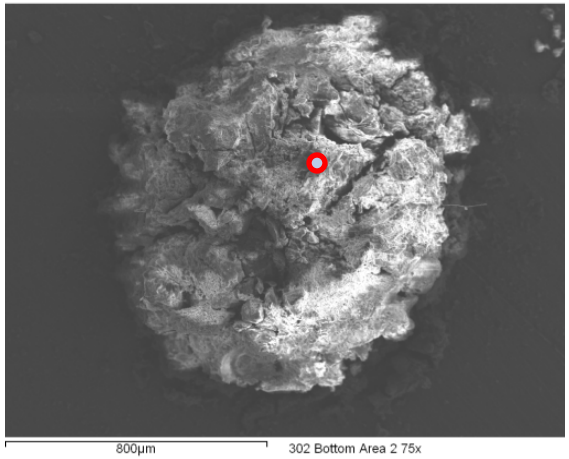
Al Coupon Results: 3 Month Exposure, Descaled - Optical Micrographs

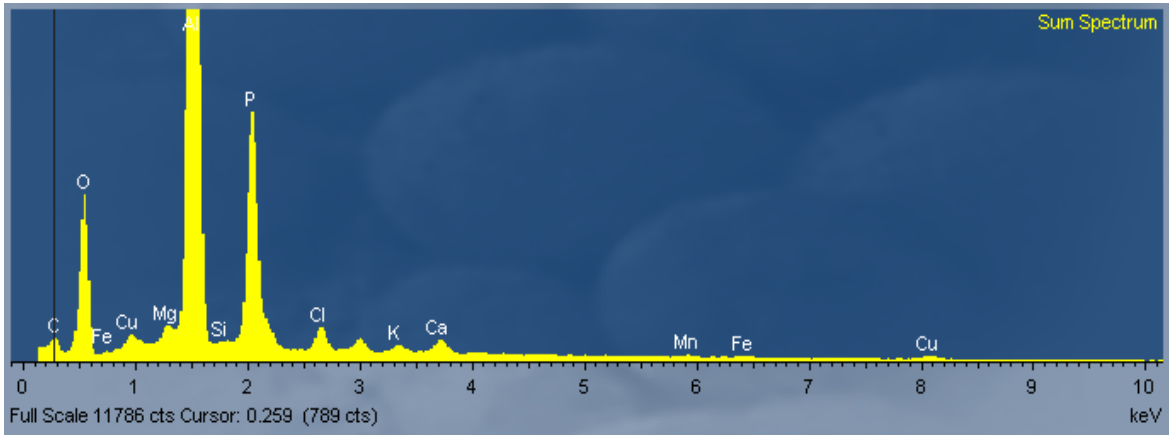
	Bacteria Consortia	Fungi Consortia	Combination	Buffer Only
Top				
Bottom		 	 	

Aluminum Coupon Results: 3 Month Exposure, Wiped (Representative Samples)

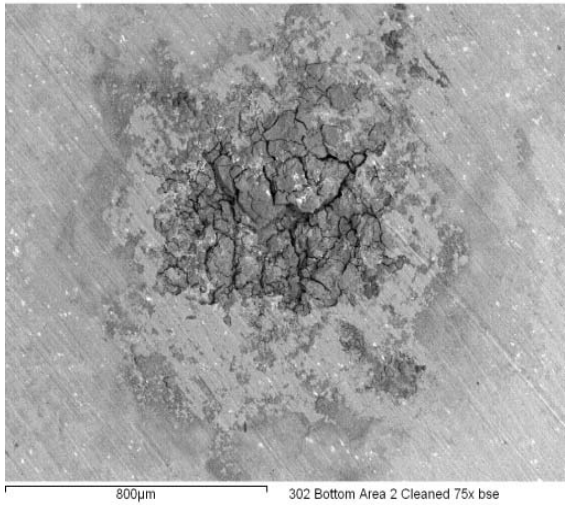
Coupon ID 302 **Bacteria Consortia**

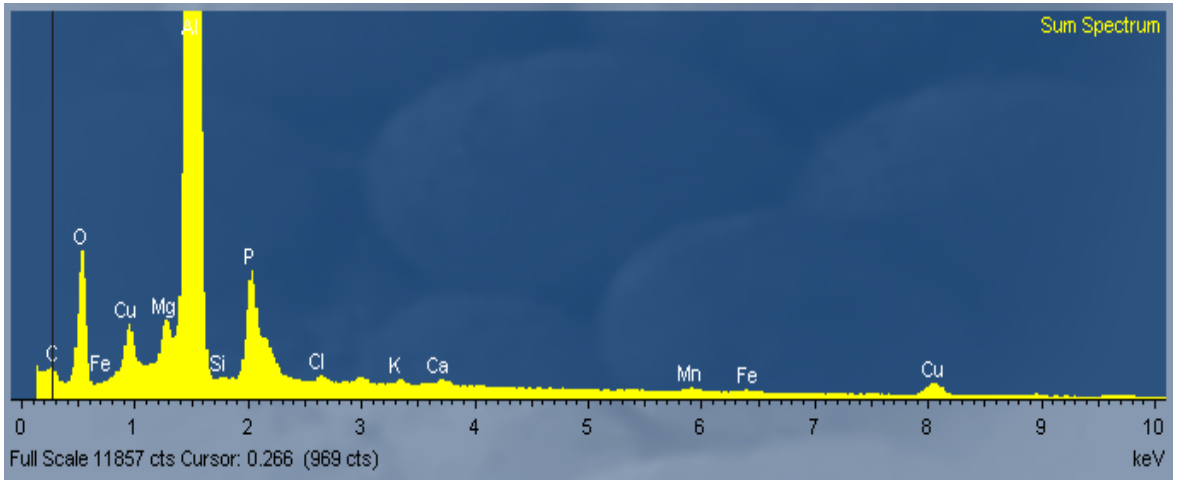
As-tested





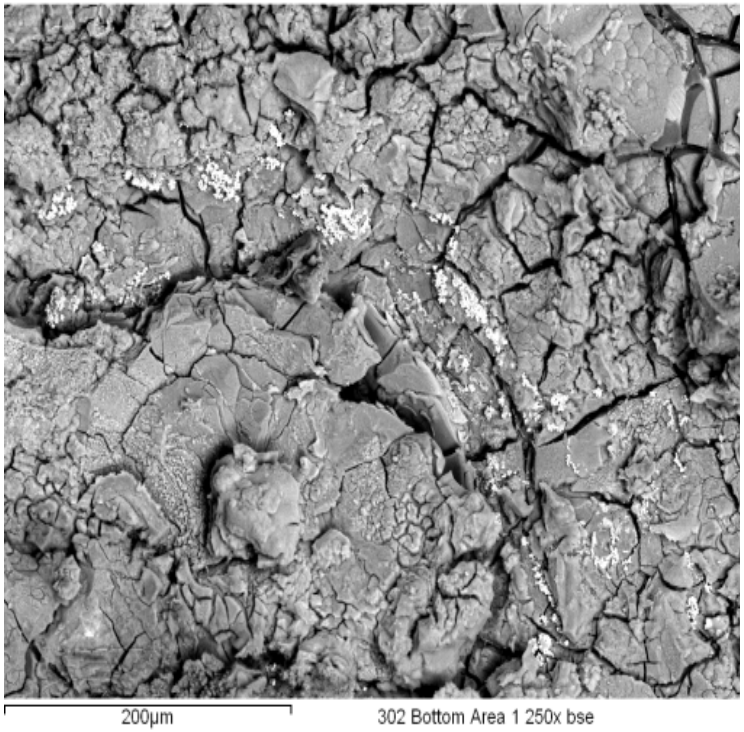
As-wiped

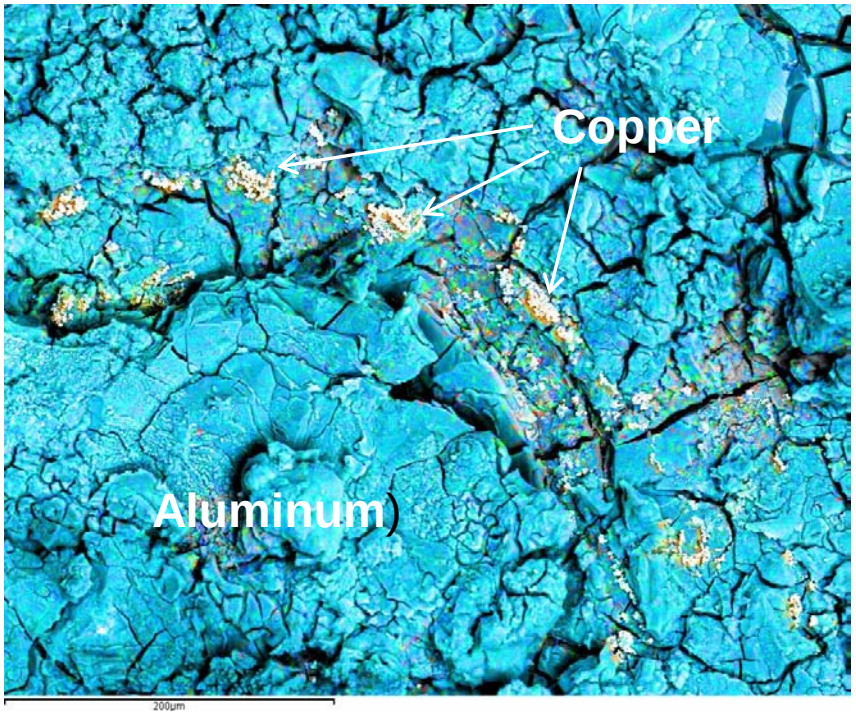




Aluminum Coupon Results: 3 Month Exposure, Cleaned (Representative Samples)

Coupon ID 302 Bacteria Consortia



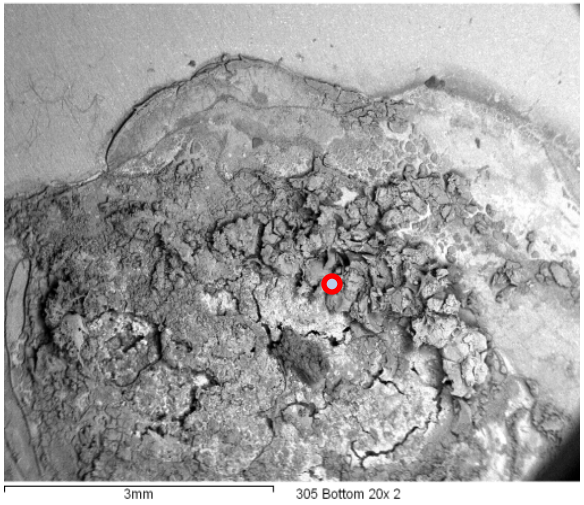


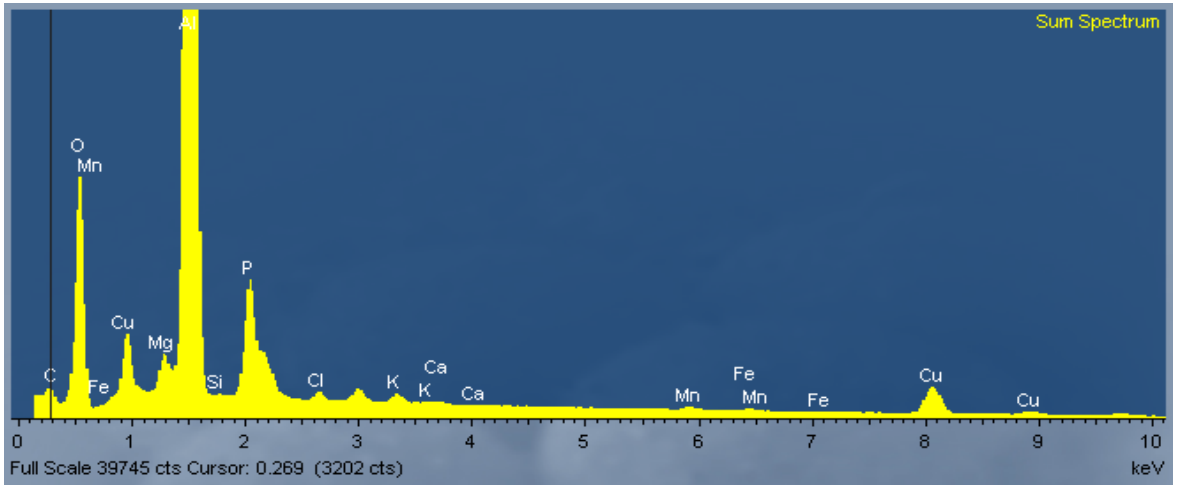
Dried biofilm and corrosion products inside pit area, with evidence of selective metal ion extraction or dealloying from metal or alloying networks

Aluminum Coupon Results: 3 Month Exposure, Wiped (Representative Sample)

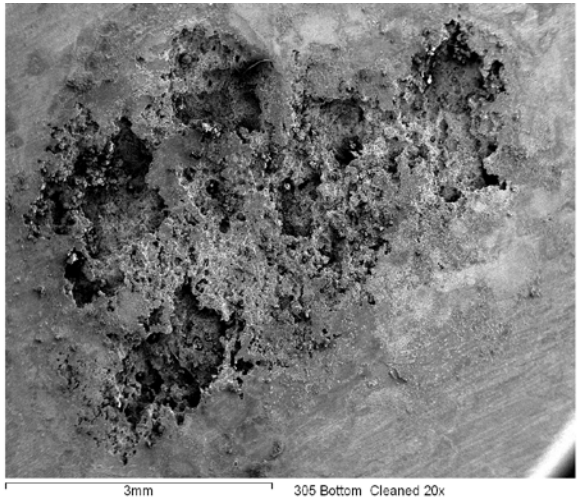
Coupon ID 305 **Fungi Consortia**

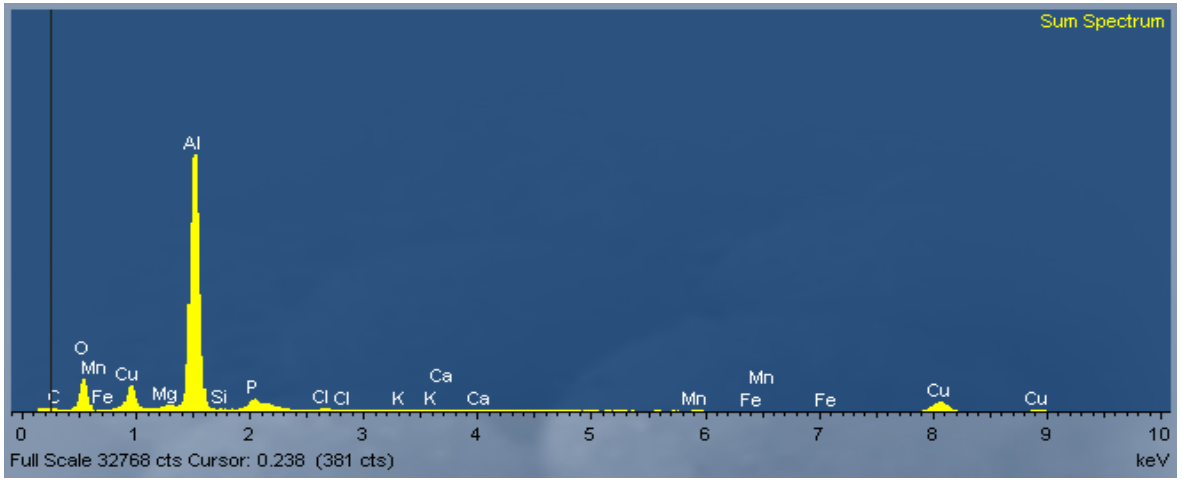
As-tested





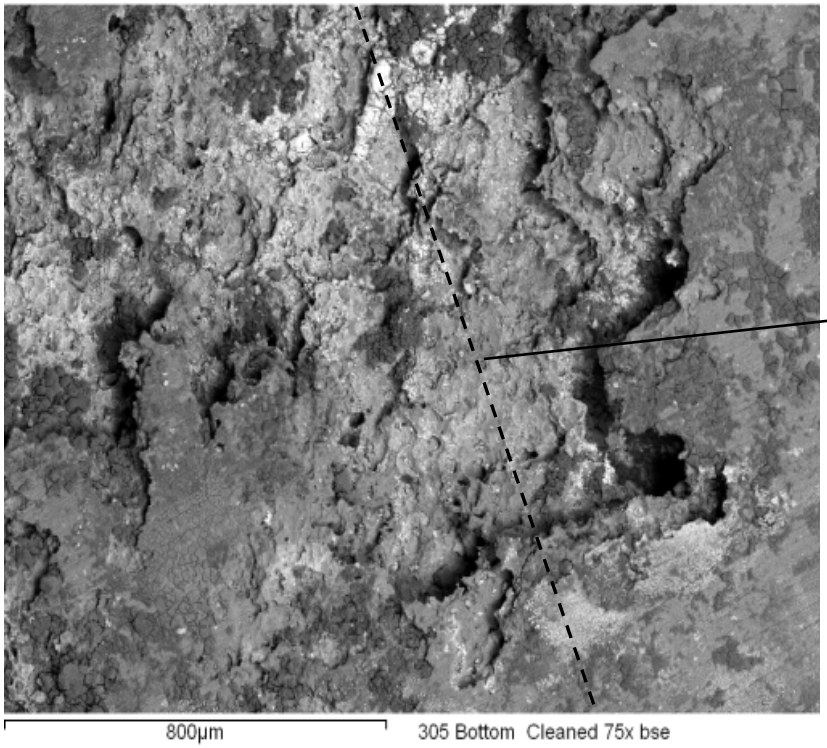
As-wiped

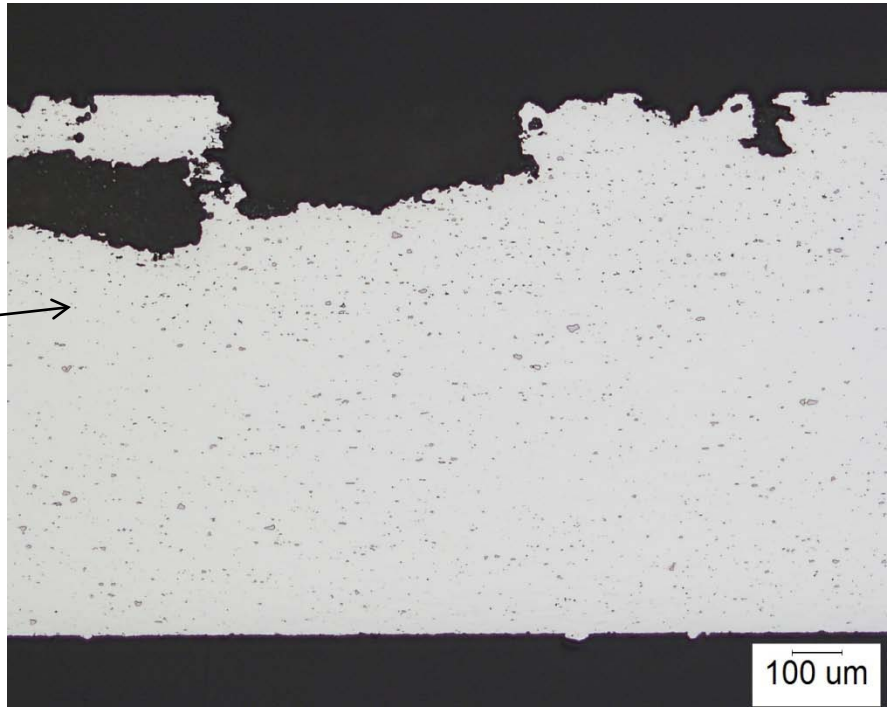




Aluminum Coupon Results: 3 Month Exposure, Descaled (Representative Samples)

Coupon ID 305 Fungi Consortia



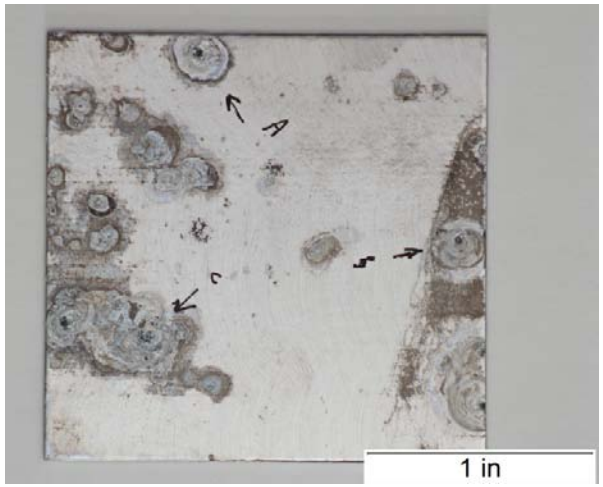


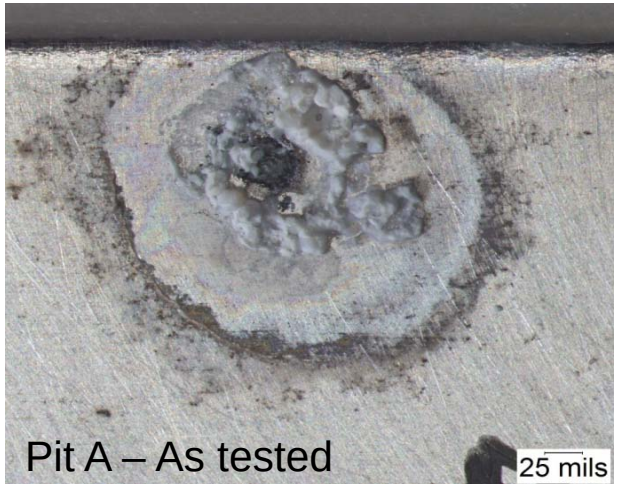
Aluminum Coupon Results: 3-month exposure

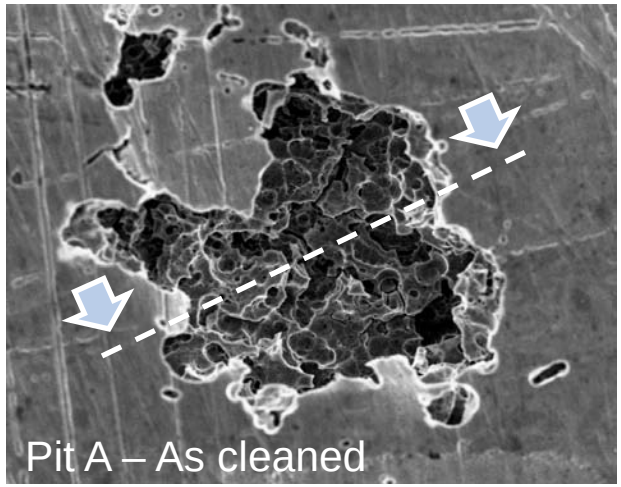
Coupon ID	Test Solution	pH	Discoloration		Pitting, max (mils)	Comments
			Top	Bottom		
701	Buffer only	7	3L-NP	G-NP	~5 T	General staining only – T/B
702	Buffer only	7	None	E-1P	~3 B	1 area of localized pitting - B
703	Buffer only	7	1G-3P	G-NP	~2 T	General staining only – T/B
704	Buffer only	7	None	3L-1P	<5 B	Localized staining – B only
705	Buffer only	7	None	None	0	No staining detected – T/B
706	Buffer + Biocide	5.5	2L-1P	2L-1P	~1 B/3 T	Localized staining only – T/B
707	Buffer + Biocide	5.5	2L-1P	1L-1P	~1 T/B	Localized staining only – T/B
708	Buffer + Biocide	5.5	2L-1P	G-NP	~3 T	Localize staining only – T/B
709	Buffer + Biocide	5.5	2L-NP	1L-1P	~5 B	Localized staining/etching – T/B
710	Buffer + Biocide	5.5	4L-NP	G-1P	~1 B	Localized staining – T/B
711	Water only	5.5	None	None	0	No staining detected – T/B
712	Water only	5.5	None	None	0	No staining detected – T/B
713	Water only	5.5	None	1L-1P	~1 B	Localized staining – B only
714	Water only	5.5	None	None	0	No staining detected – T/B
715	Water only	5.5	None	None	0	No staining detected – T/B
716	Fungal Consortia	7.5	3L-1P	G-NP	>6 T	Surface staining – B only
717	Fungal Consortia	7.5	4L-4P	G-NP	>12 T	Surface staining/localized pitting on T surfaces only
718	Fungal Consortia	7.5	1L-1P	G-NP	>20 T	Edge corrosion – T only
719	Fungal Consortia	7.5	3L-1P	G-NP	<1 T	Surface staining – T/B
720	Fungal Consortia	7.5	G-NP	None	0	No staining detected – T/B
721	F-16 Consortia	7.5	G-2P	G-5P	>15 B	Edge corrosion pits – B deepest
722	F-16 Consortia	7.5	22L-2P	G-NP	~15 T	Edge corrosion pits – T deepest
723	F-16 Consortia	7.5	3L-3P	4L-4P	~10 T	Edge corrosion pits – T deepest
724	F-16 Consortia	7.5	1L-1P	G-NP	~10 T	Edge corrosion pits – T deepest
725	F-16 Consortia	7.5	5L-5P	G-1P	>30 T/B	Edge thru-wall penetration

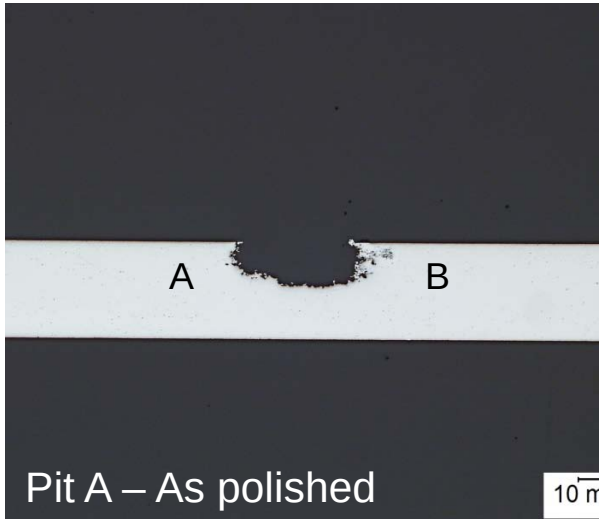
Aluminum Coupon Results: 3-month Exposure (Representative Sample)

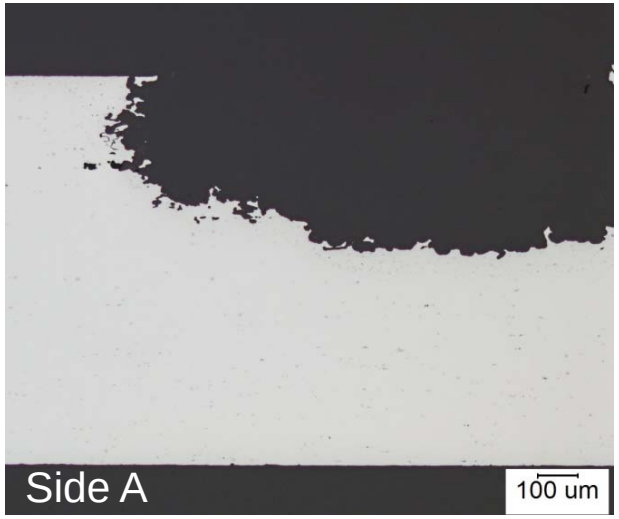
Coupon ID No. 722 (F-16 Consortia)

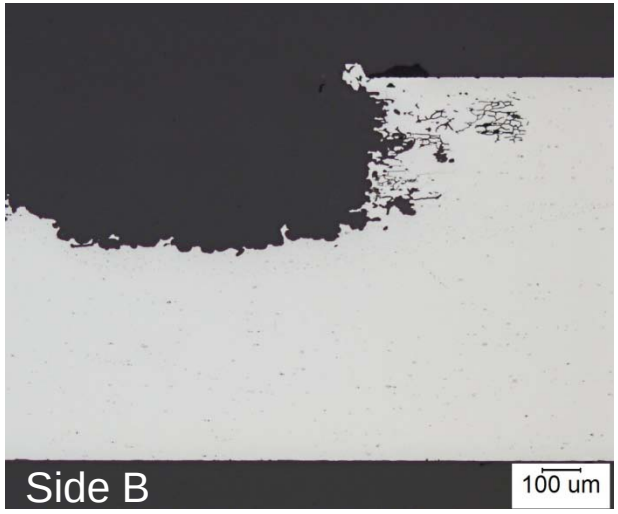






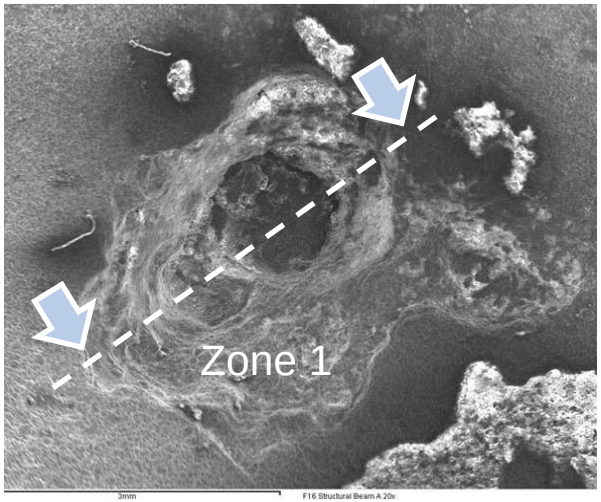


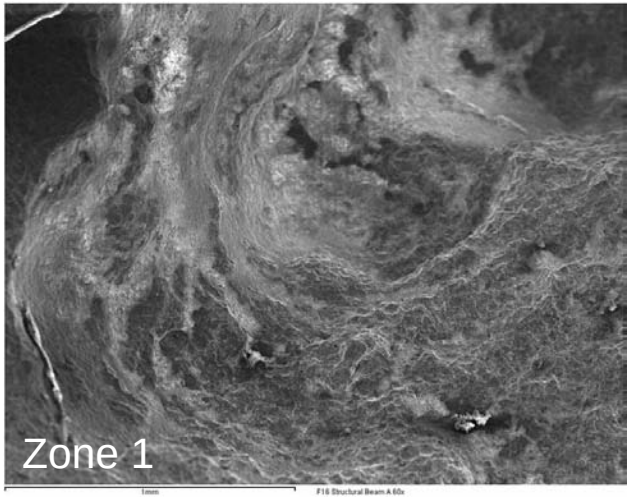


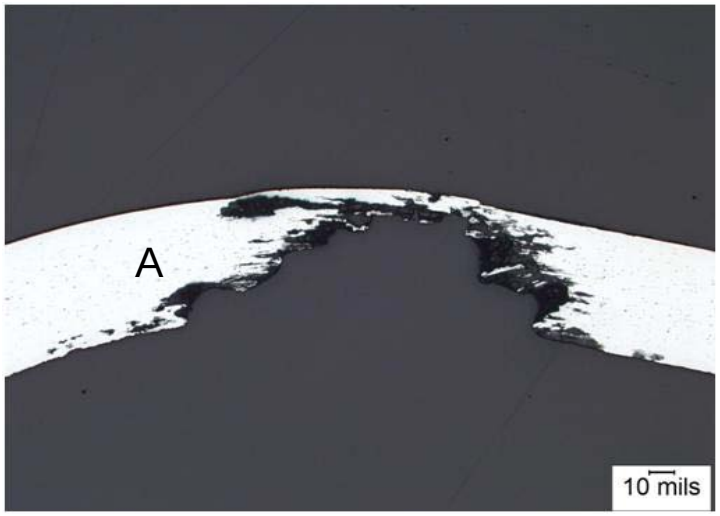


Aluminum F-16 Parts Results: In-Service Exposure (Representative Sample)

Aft Cockpit Beam







MIC Mitigation Assessment: Technical Approach

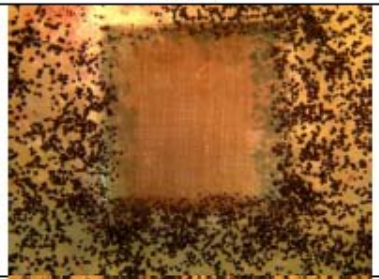
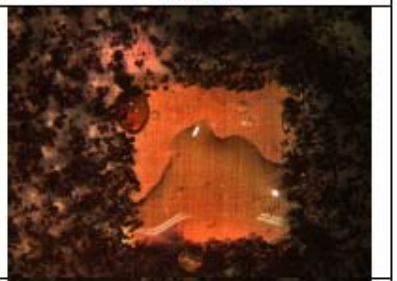
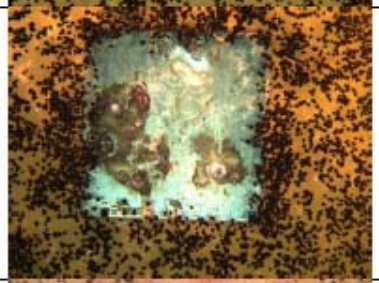
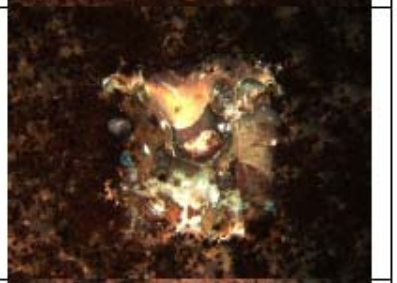
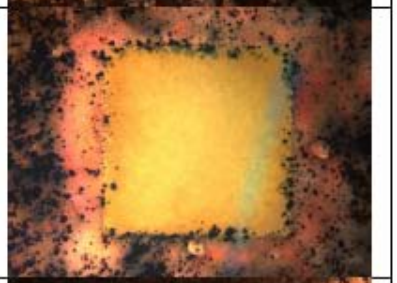
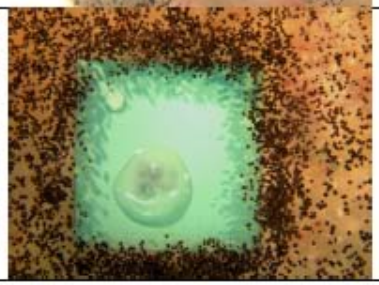
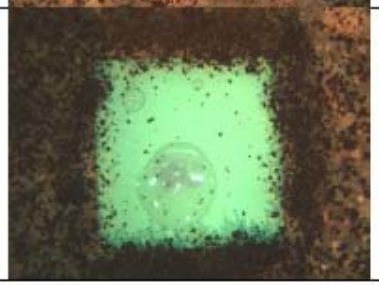
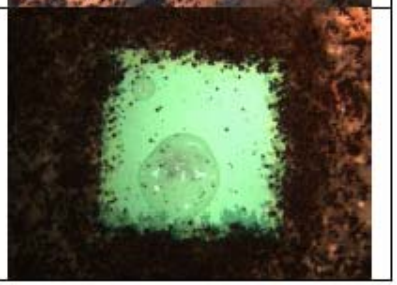
- **ASTM Test Methods**
  - E 2180-07: Standard Test Method for Determining the Activity of Incorporated Antimicrobial Agent(s) in Polymeric or Hydrophobic Materials
  - D 5590-00 (Reapproved 2005): Standard Test Method for Determining the Resistance of Paint Films and Related Coatings to Fungal Defacement by Accelerated Four-Week Agar Plate Assay
  - D 3274-09: Standard Test Method for Evaluating Degree of Surface Disfigurement of Paint Films by Fungal or Algal Growth, or Soil and Dirt Accumulation
- **Fungal Consortium**
  - *Aspergillus sp* (FI-19)
  - *Fusarium oxysporum* (FI-6)
  - *Hypocrea jecorina (FI*-1)
  - *Pleosporacea sp*. (FI-17)
  - *Ustilago maydis* (FI-13)
  - *Aureobasidium pullulans* (FI-16)
  - *Fusarium sp*. (FI-18)
  - *Penicillium oxalicum* (FI-12)
  - *Rhodoturala mucilaginosa* (FI-7)
- **Test Systems**

Test System	Description
A	Coupons on acidified Potato Dextrose Agar (aPDA); variation of ASTM D5590-00
B	Coupons on Agar slurry inoculum overlay; variation of ASTM E 2180-07
C	Coupon Suspension Test

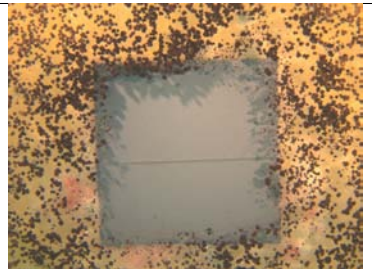
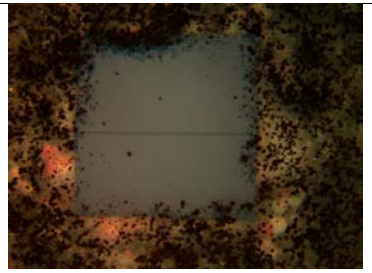
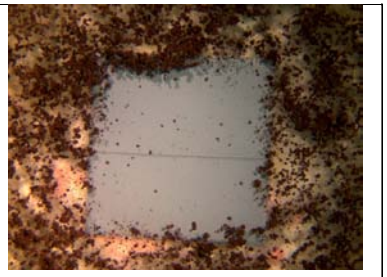
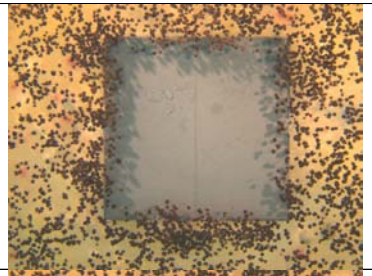
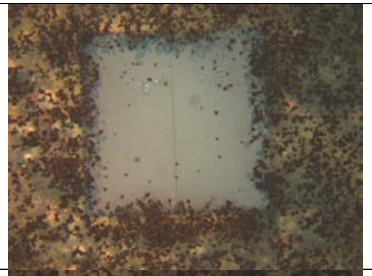
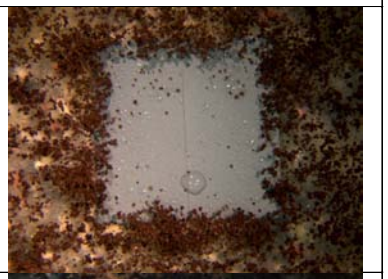
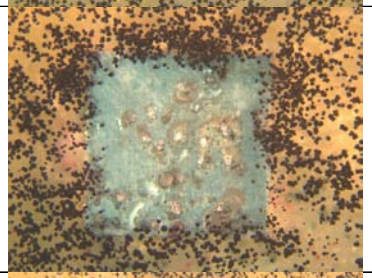
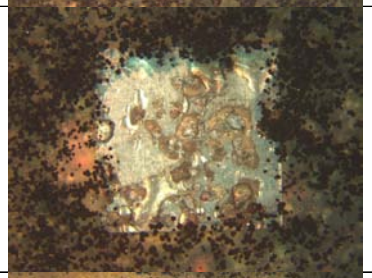
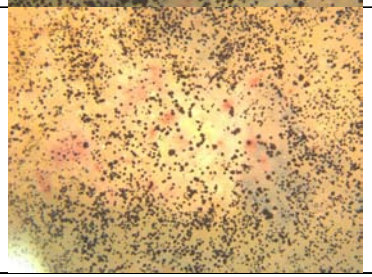
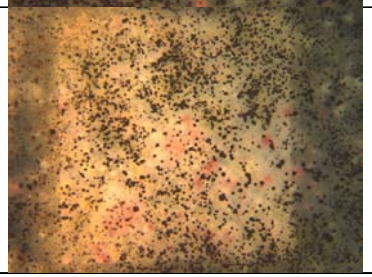
MIC Mitigation Assessment: Test Matrix

Sample Type	Sample Group	Sample Numbers	Description
Test	1	1-3	Cr^{+6} conversion coating applied to coupons spiked with fungal consortium
	2	4-6	Non-Cr^{+6} treatment applied to coupons spiked with fungal consortium
	3	7-9	Cr^{+6} conversion coating and Cr^{+6} primer applied to coupons spiked with fungal consortium
	4	10-12	Non-Cr^{+6} treatment and Non-Cr^{+6} primer applied to coupons spiked with fungal consortium
	5	13-15	Cr^{+6} conversion coating and Cr^{+6} primer and topcoat applied to coupons spiked with fungal consortium
	6	16-18	Non-Cr^{+6} conversion coating and Non-Cr^{+6} primer and topcoat applied to coupons spiked with fungal consortium
	7	19-21	Uncoated coupons spiked with fungal consortium
Positive Matrix Controls	8	22-24	Whatman #2 filter paper spiked with fungal consortium
Negative Matrix Controls	9	25-27	Cr^{+6} coated coupons; spiked with sterile water
	10	28-30	Non-Cr^{+6} coated coupons; spiked with sterile water
	11	31-33	Uncoated coupons; spiked with sterile water
	12	34-36	Whatman #2 filter paper; spiked with sterile water
Positive Antifungal Control	13	37-39	Coupons coated with a known antifungal (TBD)

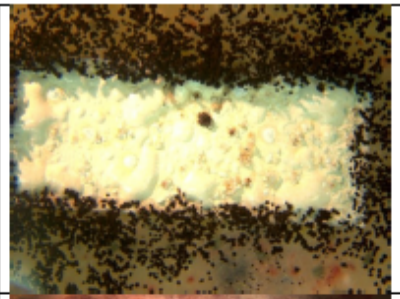
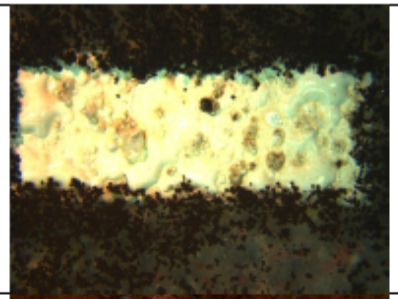
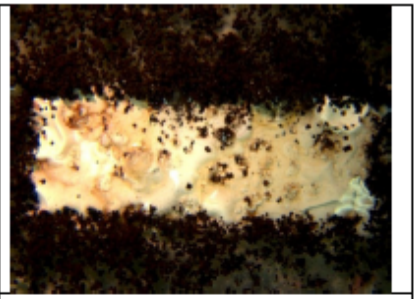
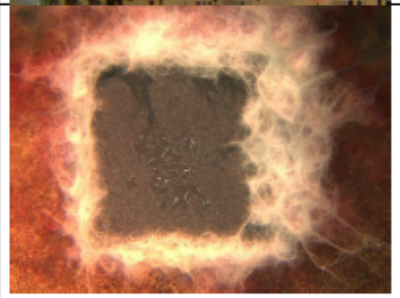
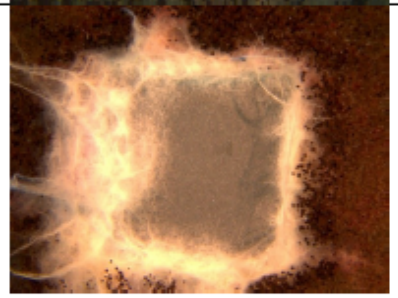
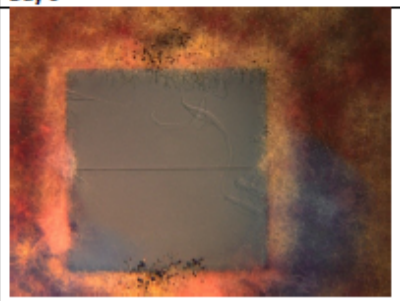
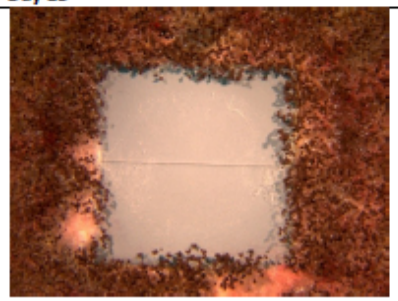
MIC Mitigation Assessment: 4-week Exposure Results

	SYSTEM I: Treated – aPDA + fungal consortium (coupon laying on fungi treated agar media)		
Coupon Type	**DAY 8**	**DAY 14**	**DAY 28**
Chrome Conversion Coating Coupon Type: A *Alodine 1200 (Henkel)*			
Non-Chrome Treatment Coupon Type: E *Prekote® (Pantheon Chemical)*			
Chrome Conversion Coating + Chrome Primer Coupon Type: B *Alodine 1200 (Henkel)* *MIL-PRF-23377H, TY 1, CL 2 (Deft - 02Y040A)*			
Non-Chrome Treatment + Non-Chrome Primer Coupon Type: F *Prekote® (Pantheon Chemical)* *MIL-PRF-23377H, TY 1, CL N (Deft – 02GN083)*			

MIC Mitigation Assessment: 4-week Exposure Results

Chrome Conversion Coating + Chrome Primer + Topcoat Coupon Type: C *Alodine 1200 (Henkel)* *MIL-PRF-23377H, TY 1, CL 2 (Deft – 02Y040A)* *MIL-PRF-85285D, TY 4, CL H (Deft – 99GY001)*			
Non-Chrome Treatment + Non-Chrome Primer + Topcoat Coupon Type: G *Prekote® (Pantheon Chemical)* *MIL-PRF-23377H, TY 1, CL N (Deft – 02GN083)* *MIL-PRF-85285D, TY 4, CL H (Deft – 99GN001)*			
Uncoated Coupon Type: D *Bare Al2024-T3* *(Negative Control)*			
Whatman Paper *(Positive Control)*			

MIC Mitigation Assessment: Exposure Results

Bunge Silver Coating Coupon Type: H *Proprietary Coating w/ Silver Inhibitor*			
Non-Chrome Treatment + Mg-Rich Primer Coupon Type: I *Prekote® (Pantheon Chemical)* *Aerodur 2100 (Akzo Nobel Aerospace)*	 Day 6	 Day 13	N/A
Non-Chrome Treatment + Mg-Rich Primer + Topcoat Coupon Type: J *Prekote® (Pantheon Chemical)* *Aerodur 2100 (Akzo Nobel Aerospace)* *MIL-PRF-85285D, TY 4, CL H (Deft – 99GY001)*	 Day 6	 Day 13	N/A

Conclusions

- 17 bacterial & 16 fungal species (common environmental isolates)
  - Minimal impact to health & safety
- Fungal species promote MIC of Al2024-T3 alloy
- Intergranular attack with selective metal ion extraction
- Hexavalent chromium has biocidal effect

Points of Contact

Mr. John Stropki

Battelle Columbus Operations

(614) 424-5414

stropki@battelle.org

Mr. Paul Hoth

Hill AFB, UT

(801) 775-4889

paul.hoth@hill.af.mil

Mr. James Tankersley

Battelle Dayton Operations

(937) 258-6724

tankersleyj@battelle.org

Questions??

Thank you!